Wide-area Technologies and Services in the Trans-Pacific High Data Rate (HDR) Satellite Communications Experiments

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ABSTRACT

In 1993, a proposal at the Japan-U.S. Science, Technology, and Space Applications Program (JUSTSAP[i]) workshop, organized by the State of Hawaii, lead to a subsequent series of satellite communications experiments and demonstrations, under the title *of Trans-Pacific High Data Rate Satellite Communications Experiments*. These experiments and demonstrations were designed to help explore and develop satellite communications techniques, standards, and protocols in order to determine how best to incorporate satellite links with fiber optic cables to form high performance global telecommunications networks.

This paper describes the technologies and services used in the experiments and demonstrations using the Trans-Pacific high data rate satellite communications infrastructure, and how the environment tasked protocol adaptability, scalability, efficiency, interoperability, and robustness. In subsequent work, the use of IPv6 differentiated services, reliable multicast, high-definition multi-party conferencing and data sharing, and increasing types of distributed application services over a combination of broadband satellite links and terrestrial dense-mode wavelength division multiplexing connections will be examined.

As people, organizations, and resources become more distributed and mobile in nature, a global information infrastructure involving broadband satellites facilitates the bridging of distant geographical areas, and makes resources available to anyone, anywhere, at anytime. In such an environment, the ability to transmit large amounts of data in a timely manner, effectively share resources such as computing clusters, and process information in a distributed manner – on a global and perhaps interplanetary scale – becomes more important, and the distinction between communication networks and distributed systems becomes less clear. The increasing distribution of users and systems brings with it issues of scale, heterogeneity, robustness, and interoperability [7-9]:

- *Scale:* Evolving systems are serving increasing number of users: from one to several users per server of recent past to easily hundreds and thousands of users today. A system must use its resources effectively and efficiently, and should possess favorable scaling properties.

- *Heterogeneity:* Various types of systems are expected to work together. The equipment in a large system would represent a spectrum of differences in terms of speed, capacity, functionality, etc. The range may include institutional-level equipment close to high bandwidth communications backbones to end-users-level equipment in homes or on the road. A desirable system should accommodate different components simultaneously and deal effectively with such variations.

- *Robustness:* An ideal solution for a large-scale system could be one that can configure itself autonomously. It would permits a system to adapt to changing conditions with minimal operator intervention. For instance, link outages and network partitioning in a large-scale system should not be seen as an exception but a norm. A robust system, therefore, needs to deal with such challenges in a graceful way without adversely affecting a large number of users.

- *Interoperability:* Distribution, scale, and heterogeneity mean increased system dynamics. A robust interoperable solution should permit different systems to operate together efficiently. The involvement of new systems, such as broadband satellites and wireless mobile networks, tasks traditional protocol mechanisms and brings out new performance and interoperability issues not previously relevant.

The Trans-Pacific experiments and demonstrations help examine communications issues in these context through implementing a series of activities including the high definition video experiment, the visible human digital library/distributed processing demonstration, and the remote astronomy distance learning/collaborative discussion application. The high definition video experiment demonstrated the transmission of high volume, timing-critical digital video streams between Los Angeles and Tokyo, and showed the feasibility of real-time, remote cinematography post-production at locations not served by terrestrial high speed networks or where such an infrastructure is not feasible. The *Visible Human* tele-medicine and *Remote Astronomy* distance education demonstrations and their use of distributed systems technologies provided an example of how students and perhaps the general public around the world could work as a virtual team under one roof, process information cooperatively in a distributed manner, share resources and collaborate with each other as if they were next to each other.

These activities would help study and develop new technologies and service models in a global information infrastructure, and can span to include activities in global-scale virtual presence, solar system internetwork, disasters mitigation, and other high data rate, distributed applications.

PHASES ONE AND TWO OF THE TRANS-PACIFIC EXPERIMENTS AND DEMONSTRATIONS

Phase 1: High Definition Video Experiment

In the Phase 1 high definition video experiment, source material was transmitted and composited in real-time between Los Angeles and Tokyo, demonstrating that satellites can deliver digital image traffic at data rates up to Asynchronous Transfer Mode (ATM) OC-3 rate (155 Mbps) and with quality comparable to that of fiber optic cables. Also, it showed the effectiveness of modern broadband satellites in the global information infrastructure, linking locations where terrestrial fiber optic infrastructure is not available or not feasible. The experiment involved the use of two broadband satellites and three terrestrial fiber optic networks, including one in the State of Hawaii.

In the traditional way of film-making, performing blue/green-screen cinematography with photographic materials often takes many iterations and weeks between the director and the film laboratory to produce images matching the director's vision. The digital virtual studio concept demonstrated by the experiment would allow the post-production processing to be done in real-time and from virtually any location on the global. The results may also be viewed at remote locations using portable HDV monitors. This made possible the instant review of compositing results by the director, and allowed immediate changes by the remote cinematography team to meet the director's liking. The real-time post-production activities therefore significantly cut down on the amount of time needed for the compositing process, as well as shorten the length of time a cinematography team and props needed to be deployed at a remote location.

The HDV streams were transmitted over ATM connections using MPEG-2 compression. The output data rates of the experimental HDV codec used could be selected from 22.5 Mbps, 60 Mbps, and 120 Mbps. The 22.5 Mbps mode was used in the experiment. The experimental device had a small buffer, and therefore required strict timing synchronization to prevent overrun/underrun situations. An off-sync condition resulting from cell-loss affected the video in the way of frozen images (freeze-frame). There were no large, scrambled blocks or distorted audio as reported in other implementations [10, 11]. In this way the codec robustly handled the cell-loss condition. The codec was interfaced to the Trans-Pacific network using ATM AAL-5 through a Cell Layer Assembly and Disassembly (CLAD) device. The MPEG-2 codec transformed the video stream into ATM cells for AAL-5. Typically, AAL-1 would be used to compensate delay variation for constant-bit-rate (CBR) applications, since AAL-5 was not meant to have such function. The experiment demonstrated that the Trans-Pacific satellite/terrestrial hybrid network provided a high quality link, which did not require AAL-1 function to be used.

The highly successful experiment resulted in the initiation of several new satellite systems and techniques for post-production processing and distribution of digital cinematography products. Coupled with advanced network technology, such as reliable multicast, efficient *virtual studio* and *digital theatre* concepts would become possible anywhere, at anytime.

Phase 2: Visible Human And Remote Astronomy Demonstrations

The Phase 2 demonstrations in Year 2000 included Visible Human and Remote Astronomy. The tele-medicine, or *Visible Human* demonstration, used the network to conduct remote, collaborative medical processes between the National Library of Medicine (NLM) of the United States National Institute of Health (NIH) in Bethesda, Maryland, and the Sapporo Medical University (SMU) in Sapporo, Japan. The *Remote Astronomy* demonstration afforded students hands-on ability to control a remote telescope located at the Mt. Wilson Observatory, California, simultaneously from their classrooms in Japan and across the United States. The demonstrations involved two broadband satellites and terrestrial fiber optic networks in Canada, Japan, and the United States.

Visible Human

The Visible Human tele-medicine demonstration showed a distributed application model enabling interactive biomedical image segmentation, labeling, classification, and indexing to take place over large images on a global scale. It involved a digital image library of volumetric data representing a complete, normal adult male and female cadaver (*The Visible Human Project*) currently residing at the NLM in Maryland. The thinly sliced images in the datasets are of cryosections derived from computerized tomography and magnetic resonance. Due to the size and international importance of the dataset, multilingual labeling of the dataset was proposed. The model facilitated multi-lingual access to the datasets through interactive *whiteboard* medical-image-based consultation, with multi-lingual assistance for collaborative work between medical researchers in different countries. Available global-scale high speed access to an anatomical segmented human anatomy atlas would be a vital resource for biomedical researchers worldwide.

The demonstration involved software tools to show sections of a human body, and enabled a researcher to make an interactive segmentation in order to recognize each anatomical object. Also, it calculated and filled areas in the segment and rendered them in a distributed manner. This would be followed by the attachment of anatomical terms to the objects working with the NLM's Unified Medical Language System and creating a multilingual object database. Visible human data would then be transferred to and from the researcher world-wide over a high performance network. Processing of large datasets would be expedited and simplified with available computational resources at various locations. Transmission Control Protocol (TCP) gateways for communication over satellites were also installed on both sides of the Pacific to enhance transmission performance over the satellite links.

Remote Astronomy

The Remote Astronomy tele-education demonstration created a wide-area environment for distance learning and collaborative discussions/observations using IP based teleconference (H.323 and multicast) and AFS distributed file system technologies. The remote astronomy system helped bring a remotely controlled telescope and charge-coupled device camera in a real-time, hands-on, interactive environment to students and even the general public around the world.

The demonstration consisted of global-scale joint observations, distributed image access, and instruction sessions by an astronomer in Pasadena to students located in Japan and the United States. Instructors from Soka High School and astronomers from the California Institute of Technology, Mt. Wilson Institute, and the University of Maryland also participated. Observation sessions would start at 9 p.m. on the United States West coast with other participants in the United States and Japan logging into the videoconference server and the Mt. Wilson telescope server at the beginning of the session. Students in Japan would be participating in the afternoons in Tokyo. The astronomer in Pasadena would then lead lectures and observations with themes such as the structures of galaxies, lives of stars, and where are all the stars. Students and other participants in the US and Japan were asked to control the telescope in turn, and the images acquired by the controlling site were distributed via AFS distributed file system to all other participants. Images from the Hubble Space Telescope archive images were also used to compare and contrast with those taken with the Mt. Wilson telescope. All participants were able to observe each other's activities as if all were sitting in one room. It would be possible for one site to be responsible for taking pictures, while others carrying out image processing on the pictures taken, with results for all participants to see.

For the Phase 2 IP-based demonstrations, the large bandwidth delay product of the satellite links on TCP were mitigated by the use of special performance-enhancing gateways. The use of distributed storage systems and local processing would help enhance communication performance in increasing the amount of useful data returned. For applications that are not accelerated by the gateways, such as distributed file systems, they would experience lower throughput over satellite links if the parameters were not suitably tuned to reflect the broadband links. Many of these performance issues in distributed systems were similar to the well publicized TCP-over-satellite issues on window sizes, timer settings, loss recovery mechanisms, and acknowledgement schemes.

It is therefore important to consider at onset the characteristics of emerging high speed, long distance networks on protocol mechanisms and their designs in all types of communications and distributed systems. Perhaps an evolution path should be defined early on to facilitate the future integration of such networks.

TOWARDS A HIGH PERFORMANCE GLOBAL INFORMATION INFRASTRUCTURE

The capabilities afforded by an emerging information infrastructure of the global scale emphasize the distributed nature of today's information systems. People, resources, and organizations are becoming more distributed. Powerful communications networks serve to connect people at distant places, permit sharing of resources such as computers, storage, and observatories. The reach of today's users is farther than ever before. An ever-blurring boundary between network and distributed systems in a wide area information infrastructure would have desirable properties in providing transparent access to users anywhere and facilitate people over wide geographical areas to work together as if under one roof.

High definition systems provide the necessary video quality to enhance the virtual presence experience. Such systems, generating large volume of time-critical data, require strict synchronization between all equipment in the network. Cutting edge compression techniques, coupled with layered encoding, would permit equipment of differing capabilities to communicate with each other. For instance, users on a high bandwidth backbone would receive high quality video, while those on a lower bandwidth edge networks would receive the same video but with lesser quality [12-13].

Multicast is well suited for applications that are distributed in nature. Examples of such applications include tele-education, video-conferencing, digital libraries, wide-area data distributions, etc. The use of multicast technology would be important to mitigate the ever-increasing demand for bandwidth, such as those seen in the Trans-Pacific series of experiments thus far. The issues such as local error recovery, reliability mechanism, receiver heterogeneity, and scalability in a global scale infrastructure involving the characteristics of broadband satellites — as well as the need to carry time critical traffic to users that are becoming ever more mobile — offer rich areas for additional research.

One of the challenges in the current Internet infrastructure is the amount of quality of service (QoS) that a network can provide on the global scale. While it is possible to obtain a high level of QoS over dedicated IP configurations and over a small subset of the network, the effort in implementing the same level of QoS in the global Internet as required by applications such as the high definition video experiment would be significant. The rate at which emerging research results could be deployed on a global scale would most likely depend upon suitable business cases, and would undoubted be expedited if research and other large organizations could start making use of them in their daily operations.

Future experiments using multicast, mobility, and differentiated services for IPv6 over dense-mode wavelength division multiplexing will be candidates for study. The activities could include applications in the area of global-scale virtual presence, solar system internetwork, disasters mitigation, and other high data rate, distributed applications.

CONCLUSION

In 1993, a proposal at the Japan-U.S. Science, Technology, and Space Applications Program (JUSTSAP) workshop, organized by the State of Hawaii, lead to a subsequent series of satellite communications experiments and demonstrations, under the title *of Trans-Pacific High Data Rate Satellite Communications Experiments*. These experiments and demonstrations, initiated in 1996, were designed to help explore and develop satellite transmission techniques, standards, and protocols in order to determine how best to incorporate satellite links with fiber optic cables to form high performance global telecommunications networks.

As people, organizations, and resources become more distributed and mobile in nature, a global information infrastructure involving broadband satellites serves to bridge wide geographical distances and make information and equipment resources available to anyone, anywhere, at anytime. In such an environment, the ability to effectively share resources and capabilities in a distributed manner — on a global or even an interplanetary scale — becomes important, and the distinction between communications networks and distributed systems becomes less clear.

This paper describes the technologies and services used in the experiments and demonstrations using the trans-Pacific high data rate satellite communications infrastructure, and how the environment tasked protocol adaptability, scalability, efficiency, interoperability, and robustness. In subsequent work, the use of IPv6 differentiated services, [reliable] multicast, high-definition multi-party conferencing and data sharing, and increasing types of distributed application services over a combination of broadband satellite links and terrestrial dense-mode wavelength division multiplexing connections will be examined.

PARTICIPANTS

The Canadian participants included AT&T Canada, BCnet, CANARIE, Communications Research Centre (CRC), and Teleglobe Inc.; the Japanese participants included Communications Research Laboratory (CRL), Institute of Space and Astronautical Science, Japan Ministry of Posts and Telecommunications (MPT), JSAT Corporation, Inter-Ministry Research Information Network (IMNet), Japan Gigabit Network, Kokusai Denshin Denwa Company, Limited (KDD), Mitsubishi Electric Corporation, Nippon Telegraph and Telephone Corporation (NTT), NTT Communications, Sapporo Medical University, Soka High School, and Sony Corporation; the U.S. participants Apple Federal Systems, ATDNet, AverStar Inc., California Institute of Technology, Comsat, Crossroads High School, George Washington University, GTE Hawaiian Tel, Lockheed Martin, Mentat Inc., Mt. Wilson Institute, NASA Glenn Research Center, NASA Goddard Space Flight Center, NASA Headquarters, NASA Integrated Services Network, NASA Jet Propulsion Laboratory, NASA Research and Education Network, National Library of Medicine/National Institute of Health, Newbridge Networks Inc., Pacific Bell/CalREN, Pacific Space Center, Sony Pictures High Definition Center, Science, Technology and Research Transit Access Point (STAR-TAP), State of Hawaii, Teleglobe USA, Thomas Jefferson High School, Tripler Army Medical Center, and University of Maryland; international organizations, Asia-Pacific Advanced Network (APAN) and INTELSAT, also participated.

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INTRODUCTION

Government, academic, and industry teams in Canada, Japan and the United States have begun a series of Trans-Pacific experiments to develop and demonstrate the role of satellite communications in the Global Information Infrastructure (SC/GII). These experiments and demonstrations will help explore and develop satellite communications techniques, standards, and protocols in order to determine how best to incorporate satellite links with fiber optic cables to form high performance global telecommunications networks. The *Trans-Pacific High Data Rate (HDR) Satellite Communications Experiments* were initiated in 1996 as the result of a proposal by the Japan-U.S. Science, Technology and Space Applications Program (JUSTSAP), organized by the State of Hawaii. The Trans-Pacific High Data Rate (HDR) Satellite Communications Experiments included topics in high definition video transmission, collaborative remote astronomical observations, tele-medicine, tele-education, electronic commerce, and digital libraries [1-6].

The first experiment in the series to establish a dual-hop broadband satellite link for the transmission of digital high definition video (HDV) over an asynchronous transfer mode (ATM) network was the *Trans-Pacific High Definition Video Experiment* [1-3]. It demonstrated that modern broadband satellites can deliver data rate and quality comparable to terrestrial fiber optic networks, and realized the *digital studio/theatre anywhere* concept. Digital HD cinematography could be conducted from virtually any location in the world, and the results of post-production could be viewed on remote monitors and projection systems almost instantly. The successful post-production activity performed between Tokyo and Los Angeles predicated on the seamless interoperation of all the equipment between the two sites.

This was followed by Internet Protocol (IP) based experiments and demonstrations [4-6] in tele-medicine and distance-education using a combination of terrestrial fiber optic networks and two high data rate geostationary satellites for a total signal path exceeding 100,000 miles across Canada, Japan, and the United States. The use of IP based technology – with the notion of *IP-over-everything and everything-over-IP* -- facilitated the participation of students and even general users in the exciting international activities of using satellite communications in the global information infrastructure. It would also help examine issues in constructing a next generation global/solar-system-wide internetwork involving broadband satellites, and would provide an opportunity in applying cutting edge research results from reliable multicast and distributed systems communities. Moreover, the activities help study and develop new technologies and service models, and can span to include activities in global-scale virtual presence, solar system internetwork, disasters mitigation, and other high data rate, distributed applications.

The *Visible Human* tele-medicine and *Remote Astronomy* distance education demonstrations and their use of distributed systems technologies afford an opportunity for people around the world to work together as a virtual team under one roof, using resources thousands of miles away as if they were next to each other. The visible human activity demonstrated global-scale interactive biomedical image segmentation, labeling, classification, and indexing using large images; the remote astronomy activity demonstrated collaborative observation and distance education at multiple locations around the globe.

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[i] The Japan-U.S. Science, Technology, and Space Applications Program (JUSTSAP) is a cooperative program officially sponsored by the State of Hawaii, with academia, industry, and government participation.